Tiny URL- System Design Interview Question URL Shortener

Overview of the Problem Statement

A URL shortener service like TinyURL or Bitly provides a way to take long URLs and generate a much shorter version. The primary goal of this system is to allow users to:

- **Convert a long URL into a short URL**.
- **Retrieve the long URL when a short URL is accessed**.
- **Ensure scalability, efficiency, and high availability** to handle billions of URLs.

Functional & Non-Functional Requirements

Functional Requirements

1. **Shorten URL** → Given a long URL, return a short URL.
2. **Redirect to Long URL** → When a user accesses the short URL, they should be redirected to the original long URL.

Non-Functional Requirements

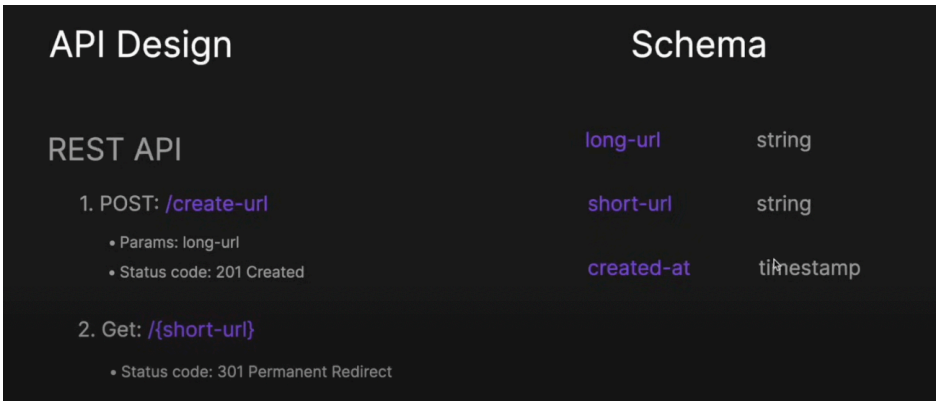
1. **Low Latency** → The system should handle URL redirections quickly.
2. **High Availability** → Ensure service reliability even under heavy load.
3. **Scalability** → Handle billions of URLs and expand as needed.
4. **Security** → Prevent URL hijacking or brute-force guessing of short URLs.

API Design & Endpoints

A **REST API** is chosen due to its simplicity and wide adoption.

API Endpoints

- **POST /create** → Accepts a long URL and returns a short URL.
  - Request: `{ "long_url": "https://example.com/some-long-url" }`
  - Response: `{ "short_url": "https://tinyurl.com/abcd123" }`
- **GET /{short_url}** → Redirects users to the long URL.
  - Request: `GET /abcd123`
  - Response: **301 Permanent Redirect** to the original URL.



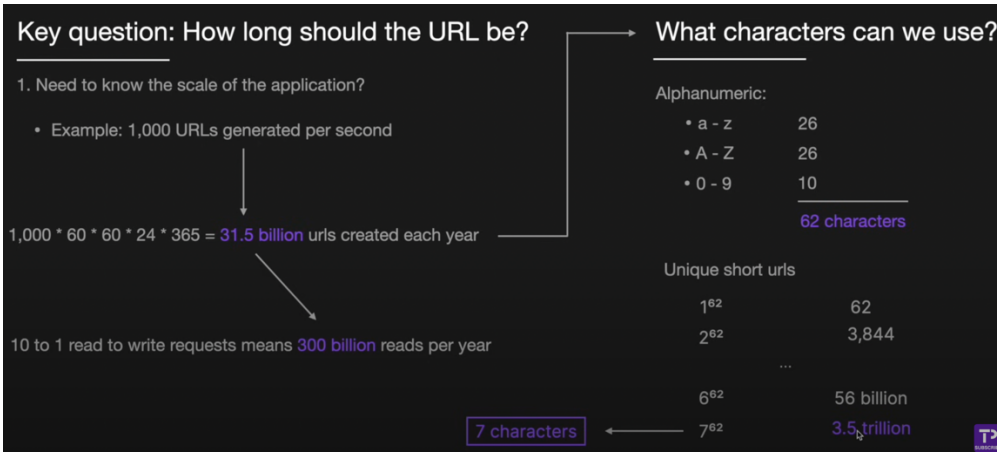
Scalability Planning & URL Space Calculation

Estimating Storage & URL Length

- The system needs to generate **1,000 URLs per second**.
- Annually, this results in **31 billion URLs**.
- Over 10 years, it requires storage for **310 billion URLs**.
- Short URLs use **7 characters**, selected from **62 characters (A-Z, a-z, 0-9)**, providing **3.5 trillion unique combinations**, ensuring enough unique IDs for future growth.

Encoding Scheme for Short URLs

- Uses **Base62 encoding (A-Z, a-z, 0-9)** to convert numbers to unique short URLs.
- Example:
    - **ID: 123456789** → Base62 Encoded **"abcd123"**
    - **Ensures short, unique, and URL-friendly identifiers.**



System Architecture

Initial Naïve Solution

1. **User sends a URL creation request**.
2. **The system assigns an incremented ID** and encodes it in Base62.
3. **Stores the mapping in a single database**.
4. **When retrieving the long URL, it performs a lookup** and redirects the user.

Issue:

- **Single Point of Failure** → If the central counter or database fails, the system crashes.
- **Limited Scalability** → Cannot efficiently handle billions of URLs.

Improved Scalable Architecture

1. **Load Balancer** → Distributes traffic among multiple web servers.
2. **Multiple Web Servers** → Handle URL generation and lookup.
3. **Distributed Database (Cassandra)** → Stores mappings efficiently.
4. **Caching Layer (Redis/Memcached)** → Stores popular URLs for faster lookups.
5. **Zookeeper for Range-Based ID Allocation** → Prevents duplicate IDs across multiple servers.

Solution Benefits:

- **Eliminates bottlenecks** and distributes load efficiently.
- **Reduces database dependency** with caching.
- **Ensures unique short URLs** using a distributed ID allocation system.

Database Choice: SQL vs. NoSQL

SQL Database (PostgreSQL, MySQL)

Advantages:

- ACID compliance ensures **strong data consistency**.
- Well-structured relational storage.

Disadvantages:

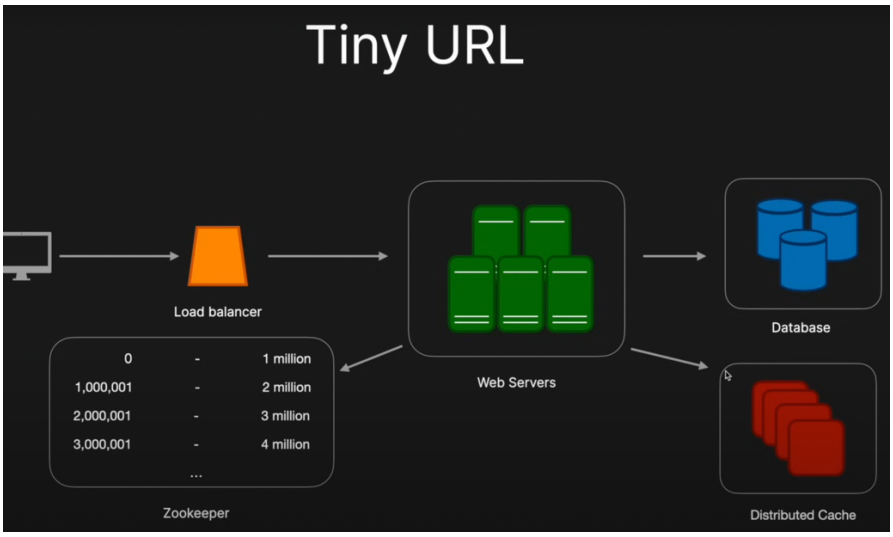
- Does not scale well for **billions of records**.
- Requires **sharding**, which adds complexity.

NoSQL Database (Cassandra, DynamoDB)

Advantages:

- **Highly scalable** for billions of records.
- Faster lookups due to **optimized distributed storage**.
- Supports **horizontal scaling** across multiple servers.

Final Choice: Cassandra due to its **efficiency for read-heavy workloads**.



Performance Enhancements

Caching with Redis/Memcached

- **Stores recently accessed short URLs in memory**.
- **Reduces database lookups**, improving response time.

Asynchronous Processing

- **Decouples heavy tasks**, allowing URL creation and logging to be handled efficiently.

Database Sharding & Partitioning

- Splits data into multiple partitions for **scalability**.
- Prevents single database overload.

Security Enhancements

- **Rate Limiting** → Prevents abuse and DDoS attacks.
- **Randomized Short URLs** → Prevents attackers from brute-forcing valid short URLs.
- **Encryption for Sensitive Data** → Secures stored URLs against unauthorized access.

Optimized Workflow Example

URL Creation Process (POST /create)

1. User **sends a request** with a long URL.
2. Load balancer **distributes request** to a web server.
3. Web server **requests a unique ID** from Zookeeper.
4. The ID is **encoded into Base62** for a short URL.
5. **Mapping is stored** in Cassandra and optionally in Redis.
6. Server **returns the short URL** to the user.

URL Redirection Process (GET /{short_url})

1. User **accesses a short URL**.
2. Server **checks Redis cache** for a stored mapping.
3. If not found, **queries Cassandra for the long URL**.
4. Returns an **HTTP 301 redirect** to the original URL.

Insights Based on Numbers

📌 **1,000 URLs per second → 31 billion URLs per year**.
🔡 **Base62 encoding** provides **3.5 trillion unique URLs**.
🚀 **Caching (Redis/Memcached)** reduces database lookups.
🔄 **Zookeeper-based ID allocation** prevents duplicate short URLs.

YT Video: https://www.youtube.com/watch?v=Cg3XIqs_-4c
My GPT chat: https://chatgpt.com/g/g-GvcYCKPIH-video-summarizer/c/67bd5b0b-53f4-800f-9da5-a82611ca3dfb